A REVIEW OF THE CURRENT AVAILABLE STUDIES

OF THE INTERFERENCE SUSCEPTIBILITY

OF VARIOUS MODULATION SCHEMES[1]

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ABSTRACT

This report reviews the current available work on interference susceptibility for various modulation schemes. Only known and published work in this area is discussed. This report classifies the interference signal into three different categories, namely, narrow-band (in-band), wide-band and pulse interference. The purpose of this report is to provide an overview of the current known work available on the interference susceptibility of' various modulation formats for these three types of interference signals. The output of this report is a recommendation for the Consultative Committee for Space Data Systems (CCSDS) regarding future direction for the interference susceptibility study.

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1. INTRODUCTION

The primary objective of this report is to review in a partly tutorial manner, the current available studies on the interference susceptibility of various signal modulation formats for three types of interference signals, namely, narrow-band (in-band), wide-band and pulse interference. The modulation formats emphasized in this report are:

-PCM/PSK/PM-Squarewave: the NRZ data is phase-shift-keyed onto the squarewave subcarrier and then phase modulated it onto the a sinusoidal carrier;

-PCM/PSK/PM-Sinewave: the NRZ data is phase-shift-keyed onto the sinewave subcarrier and then phase modulated it onto the a sinusoidal carrier;

-PCM/PM/NRZ: the NRZ data is phase modulated directly on the RF residual carrier;

-PCM/PM/Bi-Phase: the Bi-Phase (or Manchester) data is phase modulated directly on the RF residual carrier;

-BPSK/NRZ: the NRZ data is phase-shift-keyed onto the sinusoidal carrier-Note that for this modulation scheme, the RF carrier is fully suppressed;

-BPSK/Bi-Phase: the Bi-Phase data is phase-shift-keyed onto the sinusoidal carrier;

-QPSK: this modulation can be regarded as two BPSK/NRZ systems operating in quadrature

-OQPSK: this is the same as QPSK except that the In-phase (1) channel is offset with respect to the Quadrature (Q) channel by delaying it by an amount equal to half of the symbol rate;

-MSK: is regarded as a form of quadrature amplitude modulation with the modulation frequency (or clock frequency-not the carrier frequency) equal to 1/4 of the bit rate.

-GMSK: this is the same as MSK except that the transmitting pulse is shaped by a Gaussian filter.

The report is subdivided into five remaining sections. Section 2 reviews and discusses the interference susceptibility for narrow-band (in-band) interference. The pulse interference is discussed in Section 3. Section 4 presents the findings on wide-band interference. Section 5 summaries the results found in Sections 2, 3 and 4. Finally, the conclusion and recommendation of the report are presented in Section 6.

2. INTERFERENCE SUSCEPTIBILITY OF VARIOUS MODULATION FORMATS IN THE NARROW-BAND INTERFERENCE ENVIRONMENT

2.1 INTERFERENCE SUSCEPTIBILITY OF PCM/PSK/PM MODULATION FORMAT

Sue and Rosenbaum [1-4] has investigated the effects of the CW interference on the performance degradation of the PCM/PSK/PM receivers. The work done by Sue and Rosenbaum are based on the coherent detection of the residual modulated signals with squarewave [Sue, 1-2] and sinewave [Rosenbaum, 4] as subcarriers.

Sue analyzed the performance degradation of the telemetry system due to the presence of CW interference. His results are based on the assumption that the carrier tracking, subcarrier tracking and symbol synchronization are perfect. Hence, the effects of the phase error due to noise and interference in the carrier tracking loop have been neglected. In the determination of the symbol error rate (SER), P_S, Sue also assumed that the phase of the CW interference is a random variable uniformly distributed over (O, 2π). The essential of Sue's work is the use of the squarewave as subcarrier instead of sinewave. If one let S(t) and I(t) be the transmitted and interference signals, respectively, then

$$S(t) = \sqrt{2}A \sin(\omega_C t + mP(t)\, d(t) + \Theta) \tag{1}$$

$$I(t) = \sqrt{2}B \sin(\omega_C t + \omega_{SC} t + \Delta\omega t + \beta) \tag{2}$$

where A and B are the RMS voltages of S(t) and I(t), ω_C is the carrier frequency in radians/seconds, P(t) is the subcarrier, d(t) is the binary data stream, $\Delta\omega$ is the interference offset frequency in radians/seconds relative to the subcarrier frequency (ω_{SC}), ϕ is the phase angle of the desired signal S(t), m is the modulation index and β is the phase angle of the interference signal I(t) which is assumed to be a random variable with uniform distribution in [0, 2π].

For sinewave subcarrier, the SER is given by [4]

$$P_S = \frac{1}{2\pi}\int_0^{2\pi} \operatorname{erfc}\left[\sqrt{\frac{E_S}{N_0}}\,(1 + R\cos(\beta))\right] d\beta \tag{3}$$

For squarewave subcarrier, the SER is found to be [1]

$$P_S = \frac{1}{2\pi}\int_0^{2\pi} \mathrm{erfc}\left[\sqrt{\frac{E_S}{N_0}}\left(1+\frac{2}{\pi}R\cos(\beta)\right)\right]d\beta \tag{4}$$

where E_S/N_0 is the symbol Signal-to-Noise Ratio (SNR), R is the Interference-to-Signal Ratio (ISR). The SERS shown in Eqns (3) and (4) have assumed that the offset frequency of the interference signal is zero.

Based on Eqns **(3)** and (4), it is clear that, for a fixed Symbol SNR, the squarewave subcarrier makes the receiver less susceptible to in-band interference by about 4 dB. But on the other hand, the squarewave subcarrier makes the receiver susceptible to out-of-band interference due to the translation mechanism of the squarewave sub carrier.

2.2 INTERFERENCE SUSCEPTIBILITY OF PCM/PM MODULATION FORMAT

Currently, to the best knowledge of the author, the interference susceptibility for PCM/PM modulation format has not been investigated yet. Therefore, there are no results available for the effects of CW interference on the performance degradation of the PCM/PM receivers.

2.3 INTERFERENCE SUSCEPTIBILITY OF BPSK MODULATION FORMAT

A single constant amplitude, CW in-band additive interference to a coherent BPSK receiver has been analyzed by Rosenbaum [4]. The SER for this case is found to be the same as Eqn (1) for perfect carrier tracking, subcarrier tracking and symbol synchronization. However the results presented in [4] appears to apply only for the NRZ data format under perfect carrier tracking assumption. For Bi-phase data format, it is anticipated that the results will be slightly different.

The numerical results presented in [4] show that when the value of R (the interference-to-carrier signal ratio) is about -30 dB or less, the SER performance degradation due to the CW in-band interference becomes negligible. The SER performance becomes unacceptable (more than 0,5 dB) when $R \geq -15$ dB.

2.4 INTERFERENCE SUSCEPTIBILI ' OF QPSK/OQPSK MODULATION FORMATS

The effects of CW cochannel (in-band) interference on the performance of QPSK receiver have been investigated in [5-8]. [5-7] examined the effects of CW interference in the linear channel, and [8] considered the nonlinear channel.

The numerical results presented in [5-8] show that the SER performance experiences more degradation in the nonlinear channel than in the linear channel. Furthermore, the results also show that, for nonlinear channel caused by TWTA, the SER performance degradation due to the presence of cochannel interference is more than that of the channel employed hardlimiter. The different in term of symbol SNR degradation between the TWTA and hardlimiter is about 0.2 dB for the interference-to-carrier signal ratio, R, of -15 dB. In addition, for R ≈ -15 dB, the symbol SNR degradation due to the presence of CW cochannel interference for a harlimiter channel is about 1.2 dB. For linear channel, the QPSK signal is more susceptible to the CW in-band interference than BPSK signal. It was found that QPSK signal makes the receiver more susceptible to in-band interference by about 2 dB in terms of interference-to-carrier signal ratio as compared to BPSK.

2.5 INTERFERENCE SUSCEPTIBILITY OF MSK/GMSK MODULATION FORMAT

The effects of CW interference on MSK signal reception have been investigated by Shabsigh [9]. [9] also derived the SER for fading MSK signal and fading interference. It was found in [9] that MSK is more immune to CW in-band interference than BPSK. MSK has about 1.8 dB power advantage over BPSK in CW in-band interference environment,

For GMSK, currently, to the best knowledge of the author, there are no work done available in this area. Therefore, there are no results available for the effects of CW in-band interference on the performance degradation of the GM SK receiver.

3. INTERFERENCE SUSCEPTIBILITY OF VARIOUS MODULATION FORMATS IN THE PULSE INTERFERENCE ENVIRONMENT

3.1 INTERFERENCE SUSCEPTIBILITY OF PCM/PSK/PM MODULATION FORMAT

Currently, to the best knowledge of the author, the interference susceptibility for PCM/PSK/PM modulation format in the presence of pulse interference environment has not been investigated yet. Therefore, there are no results available for the effects of pulse interference on the performance degradation of the PCM/PM receivers.

3.2 INTERFERENCE SUSCEPTIBILITY OF PCM/PM MODULATION FORMAT

Currently, to the best knowledge of the author, the interference susceptibility for PCM/PM modulation format in the presence of pulse interference environment has not been investigated yet. Therefore, there are no results available for the effects of pulse interference on the performance degradation of the PCM/PM receivers.

3.3 INTERFERENCE SUSCEPTIBILITY OF BPSK MODULATION FORMAT

The deleterious effects of the pulse Radio Frequency Interference (RFI) on the (1) tracking performance of a BPSK receiver, and (2) coded Bit Error Rate (BER) performance of the nonlinear satellite communication channel have been investigated in [10-11].

[10] has examined the tracking performance of a Costas loop in the presence of single and multiple in-band pulsed RFI signals and receiver additive white Gaussian noise. [10] pointed out that when the effective RFI power is not sufficiently large to capture the loop, there exists static phase error biases which cause the loop to lock at a phase between that of the desired signal and the composite RFI. In addition, [10] also indicated that there is an increase in the rms phase jitter over the nominal design. These two effects will degrade the BER performance of the receiver. However, [10] did not evaluate the BER performance degradation due to the presence of the pulsed RFI.

[11] evaluated the coded BER degradation of a BPSK receiver due to the presence of the pulsed CW or pulsed noise RFI. This paper predicted the BER at the output of a Viterbi decoder, based on the assumption that convolutional coding is employed, The numerical results show that as the coding rate increases the coded BER degradation decreases. The bit SNR degradations due to infinite noise RFI with 10 % duty cycle and BT = 10 (B = filter bandwidth, T = bit rate) with transponder hardlimiter, $\Delta(dB)$, for $10^{-4} < BER \leq 10^{-2}$ are approximately $6.3\ dB \leq \Delta(dB) \leq 4.2\ dB$ and $3.4\ dB \leq \Delta(dB) \leq 2.7\ dB$, for coding rate of 1/2 and 1/3, respectively.

3.4 INTERFERENCE SUSCEPTIBILITY OF QPSK/OQPSK MODULATION FORMATS

Currently, to the best knowledge of the author, the interference susceptibility for QPSK/OQPSK modulation formats in the presence of pulse interference environment has not been investigated yet. Therefore, there are no results available for the effects of pulse interference on the performance degradation of the QPSK/OQPSK receivers.

3.5 INTERFERENCE SUSCEPTIBILITY OF MSK/GMSK MODULATION FORMATS

Currently, to the best knowledge of the author, the interference susceptibility for MSK and GMSK modulation formats in the presence of pulse interference environment has not been investigated yet. Therefore, there are no results available for the effects of pulse interference on the performance degradation of the MSK and GMSK receivers.

4. INTERFERENCE SUSCEPTIBILITY OF VARIOUS MODULATION FORMATS IN THE WIDEBAND INTERFERENCE ENVIRONMENT

Currently, to the best knowledge of the author, the interference susceptibility for PCM/PSK/PM, PCM/PM, BPSK, QPSK, OQPSK and MSK modulation formats in the presence of wideband interference environment has not been investigated yet. Therefore, there are no results available for the effects of wideband interference on the performance degradation of these modulation schemes.

4. SUMMARY

The current work on the interference susceptibility of various modulation schemes under three different interference environments presented in the above sections can be summarized in Table 1,

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the investigation presented above, it has been found that the interference susceptibility for CW in-band interference has been investigated for PCM/PSK/PM, BPSK, QPSK and MSK. Apparently, the effects of CW in-band interference to the performances of OQPSK, PCM/PM and GMSK receivers have not been investigated. For interference susceptibility in pulsed RF1 environments, only coded BPSK is available. Furthermore, there are no work done available on the interference susceptibility in wideband interference environment.

Based on this finding, it is recommended that the CCSDS should invest its effort in completing the investigation on the interference susceptibility for CW in-band interference. To complete the investigation in this area, the following studies are recommended:

- Investigate the effects of CW interference on the performance degradations of PCM/PM and GMSK receivers;

-Extend the current results for BPSK and QPSK to OQPSK.

For interference susceptibility in pulsed RFI environment, the following studies are recommended:

-Extend the current results for coded BPSK to uncoded BPSK, QPSK and OQPSK;

-Assess the impact of pulsed RFIs on the performance degradations of the PCM/PM. PCM/PSK/PM, MSK and GMSK receivers.

Since there are no work available for wideband interference, it is recommended that the CCSDS should also conduct a thorough investigation on the effects of wideband interferences on the performance of various modulation formats described in Section 1. “ ,

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Table 1: Research on the Work Done for Interference Susceptibility of Various Modulation Schemes

Modulation Type	CW In-band Interference	Pulsed RFI Interference	Wideband Interference
PCM/PSK/PM (Squarewave)	-Less sensitive, by about 4 dB, as compared to PCM/PSK/PM-Sine -Susceptible to out-of-band interference	Not available	Not available
PCM/PSK/PM (Sinewave)	More sensitive than PCM/PSK/PM-square	Not available	Not available
PCM/PM/NRZ	Not available	Not available	Not available
PCM/PM/Bi-Phase	Not available	Not available	Not available
BPSK	Less sensitive, by about 2 dB, as compared to QPSK	-Only available for convolutional coded BPSK -More susceptible at rate 1/2 than at rate 1/3	Not available
QPSK	More sensitive as compared to BPSK	Not available	Not available
OQPSK	Not available	Not available	Not available
MSK	Less sensitive as compared to BPSK (has 1.8 dB, in term of CNR, advantage over BPSK)	Not available	Not available
GMSK	Not available	Not available	Not available

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